The lines of the stars of intermediate temperature, like α Cygni, have long been recognised by the Harvard observers as well as by myself as presenting great difficulties.

In 1893 I wrote as follows* :—"With the exception of the K line, the lines of hydrogen aud the high temperature line of Mg at $\lambda 4481$, all the lines may be said to be at present of unknown origin. Some of the lines fall near lines of iron, but the absence of the strongest lines indicates that the close coincidences are probably accidental."

In the Harvard 'Spectra of Bright Stars' 1897, p. 5, the following words occur, relating to the same stars :—

"This system of lines should perhaps be regarded as forming a separate class, as in the case of the Orion lines, and should not be described as 'metallic,' as has just been done in the absence of any more distinctive name."

From the fact that these unknown lines have now been traced to a "proto-metallic" origin, as effectively as the unknown lines of the hottest stars have been traced to helium and asterium, we may expect that the consequences of this determination in relation to stellar classification and other connected matters, will be very far reaching. At present I am using this new spectrum consisting of enhanced lines as an explorer, in relation to some further details of stellar classification having special reference to stars of Groups III and IV in which bright as well as dark lines occur.

"On the Effects of Strain on the Thermo-Electric Qualities of Metals."

By MAGNUS MACLEAN, M.A., D.Sc. Communicated by Lord KELVIN, F.R.S. Received January 23,—Read February 2, 1899.

1. Seebeck† discovered the great effect that hardness, or softness, or crystalline structure, has on the thermo-electric properties of metals. Magnus made a number of experiments by winding a hard drawn wire on a reel. Parts of this wire were softened and annealed. When heat was applied to the parts of the wire which were between unannealed and annealed, a thermo-electric current was obtained. In this way Magnus found that the current passed from soft to hard through the hot junction for silver, steel, cadmium, copper, gold, and platinum; and that it passed from hard to soft through the hot junction for German silver, zinc, tin, and iron.

2. Lord Kelvin describes in vol. 2 of his 'Mathematical and Physical Papers' a number of qualitative experiments to determine the direction

* 'Phil. Trans.,' A, vol. 184, p. 694.

† 'Pogg. Ann.,' 1826.

of thermo-electric currents in the same metal when one part of it is left unstrained, and the other is—

(1) Permanently affected by application and removal of longitudinal stress;

(2) Permanently affected by application and removal of lateral pressure;

(3) Under a longitudinal stress (*a*) within its limits of elasticity, and (*b*) beyond its limits of elasticity;

(4) Hardened by twisting;

(5) Annealed.

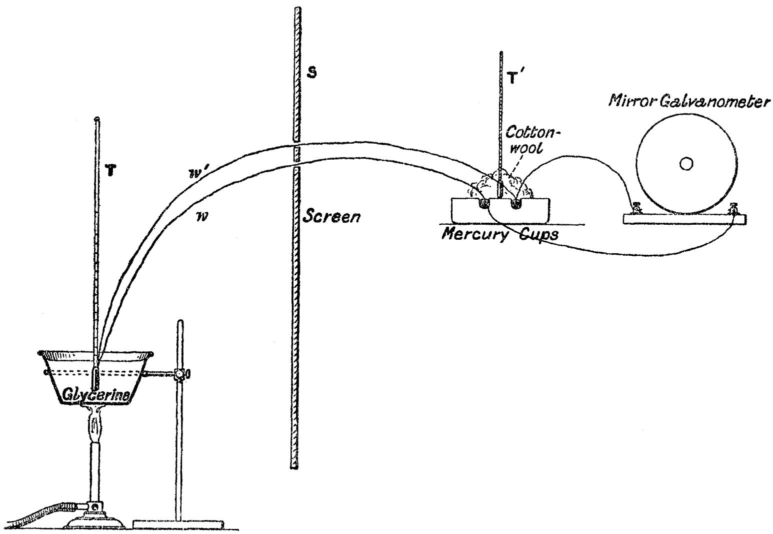
3. He showed that for iron and copper permanent longitudinal extension gave the same effect as permanent lateral contraction; and that this effect for both was opposite to that experienced by them when under a stress which caused a temporary strain. Thus for a copper wire under a longitudinal stress the current was from the strained copper to the free copper across the hot junction, and the magnitude of the current increased with the increase of the longitudinal stress. If the stress were removed and the wire left with a permanent strain, the current was now from the free copper to the strained copper through the hot junction. Similar results were got with iron, only the direction of the current was in each case opposite to the direction of the current in the corresponding case for copper. The highest temperature used in these experiments was about 100° C.

4. A summary of Lord Kelvin's results is given on pages 296 and 297 of vol. 2 of his 'Mathematical and Physical Papers.' His results for copper are given, for example, in the following table :—

Conductor.	Condition of strained conductor. Direction of current through hot junction is from 1 to 2.
Copper.........	1. Under longitudinal traction. 2. Free.
,, ...	1. Soft. 2. Permanently elongated by longitudinal traction, and left free from stress.
,, ...	1. Soft. 2. Hammered transversely.
Round copper wire	1. Annealed after being made brittle by twisting. 2. Made brittle by twisting.
,, ,,	1. Annealed. 2. Suddenly cooled.

5. To determine the *magnitude* of the thermo-electric effects obtained from any one metal, strained and unstrained, was the object I had in

view when I started these experiments. The arrangement is shown diagrammatically below. One junction of the wires was kept in a



glycerine bath which could be heated by a Bunsen burner. This junction was tied by a fine copper wire to the bulb of a thermometer T. The other ends of the wires were joined to short copper wires which served as terminals of the low resistance galvanometer used in the experiments. These junctions were wrapped in paraffin paper or cotton wool which contained the bulb of a thermometer T′, reading half degrees from 0°C. to 25° C. A paper screen S was hanging vertically between the Bunsen burner and the thermometer T′ and the galvanometer to prevent any heat from the flame reaching the rest of the circuit by radiation. These precautions were taken to make certain that all junctions, except the hot junction, would be at the same temperature.

6. The constant of the galvanometer was determined by joining a Daniell cell in circuit with the galvanometer and with a resistance of over 30,000 ohms. The electromotive force of the Daniell cell was compared with a standard Clark cell by means of a quadrant electrometer. In this way the current through the galvanometer per division deflection on the scale was determined. The sensitiveness, in preliminary experiments, was 0·612 mikroampere per division. But by different arrangements of the controlling magnets, the sensitiveness of the galvanometer as now used is 0·09 mikroampere per division. The resistance of the galvanometer, at 15° C.—the average temperature of the laboratory during the experiments—is 1·5 ohms. Thus the electro-

motive force at the terminals of the galvanometer as now used is 0·135 mikrovolt per division.

7. A considerable lag was found in the thermometer readings, and the following method was adopted to get rid of this effect. The hot junction was heated very slowly through a small range (5° C. or 10° C.) and then the Bunsen burner was drawn slightly aside so as to give approximately as much heat to the vessel which contained the glycerine as it lost by radiation. The thermometer, T, and the spot of light on the scale were simultaneously observed, and when both were seen to be steady, the readings were noted. The circuit was then immediately broken and readings taken of the galvanometer zero* and the thermometer T′.

Very often the glycerine was allowed to cool slowly, and by means of a small Bunsen flame the temperature was kept steady for a short time and readings taken. If the same precautions were taken as are described in the previous paragraph, the same deflections from zero were got for the same difference of temperature between the hot and cold junctions.

8. The metals so far tried are :—

(1) Copper wire from Messrs. Johnson and Matthey. This was pure electrotype copper wire with no impurity detected except an unweighable trace of iron.

(2) Copper wire, ordinary commercial, from Messrs. Johnson and Matthey. This was analysed† in the chemical laboratory of the University, and was found to contain :—

* It was found necessary to take the zero immediately after each reading as the zero was by no means constant. It was thought at first that the change of zero was mainly due to the suspending fibre of the mirror in the galvanometer, but a new plug and fibre did not lessen the variations of the zero during an experiment. It is most likely due to the general laboratory experiments going on simultaneously, which involve the moving of apparatus and the walking about of students with knives and keys in their pockets in the near vicinity of the galvanometer. For example, my own pocket knife at the distance of the scale from the galvanometer (a metre) gives a deflection of 10 scale divisions. The galvanometer is at a distance of 11·74 metres from the dynamo used in the electric light installation of the Physical Laboratory, the two being separated by a stone wall. The stopping or the starting of the dynamo altered the metallic zero of the galvanometer by 100 divisions. The constant of the galvanometer was tested both when the dynamo was running and when the dynamo was not running. Practically it was the same on both occasions. Nearly all the experiments were done when the dynamo was running.

† All the chemical analyses stated in this paper were given to me by Mr. Anderson, of the Chemical Laboratory of this University.

Copper	99·4	per cent.
Arsenic	0·44	,,
Lead	0·08	,,
Bismuth	trace	
	99·92	,,

(3) Copper wires, used for alloying with gold and silver, from Messrs. Johnson and Matthey. This also was analysed and it contained 99·85 per cent. of copper.

(4) Copper wire from Glover. Chemical analysis showed that it contained 98·35 per cent. of copper.

(5) Copper wire of Glover's manufacture and supposed to be soft and to have a very high conductivity. It contained 99·08 per cent. of copper and 0·22 per cent. of lead.

(6) Copper wire used in laboratory experiments. It contained 98·51 per cent. of copper.

(7) Lead wire, commercial. It contained 98·9 per cent. of lead.

(8) Lead wire, pure.* It contained 98·97 per cent. of lead.

(9) Platinoid wire obtained from Messrs. Glover.

(10) German silver wire ,, ,, ,,

(11) Reostene† ,, ,, ,, ,,

(12) Manganin ,, ,, ,, ,,

9. The size of the wire used, except for (5) (7) (8) above, was about No. 18 standard gauge. A piece of the wire was taken and drawn through a draw plate till it was reduced to about No. 24 standard gauge. This process of wire drawing subjects the wire to longitudinal extension and to lateral compression. Lord Kelvin in his experiments ('Mathematical and Physical Papers,' vol. 2 and section 3 above) showed that thermo-electric differences were in the same direction for longitudinal extension and transverse compression. For drawn and undrawn wires the direction of the current through the hot junction is from undrawn to drawn for copper, reostene, and lead, and from drawn to undrawn for platinoid, German silver, and manganin. The magnitude of the current per degree difference of temperature is given in the following table.

* These specimens of commercial and pure lead wires were obtained from Messrs. Baird and Tatlock of Glasgow. Other specimens have been ordered elsewhere for a fresh determination.

† Reostene belongs to the nickel steel group, with certain other metals as an alloy. Messrs. Glover and Co. could not give me particulars regarding it, or regarding manganin, which is composed of copper, tin, and manganese.

Conductor.	Condition of conductor. Direction of current through hot junction is from 1 to 2.	Current in mikro-ampere per degree up to 100° C.
Copper, pure electrotype, Messrs. Johnson and Matthey	1 undrawn ... ... 2 drawn	0·0057
Copper, commercial, Messrs. Johnson and Matthey	1 undrawn .... 2 drawn	0·0279
Copper, used for gold alloy, Messrs. Johnson and Matthey	1 undrawn .... 2 drawn	0·0104
Copper, commercial, Glover	1 undrawn .... 2 drawn..........	0·0068
Copper, soft, high conductivity, Glover ..	1 undrawn .... 2 drawn	0·031
Copper, laboratory	1 undrawn .... 2 drawn	0·0435
Lead, pure..........	1 undrawn .... 2 drawn	0·0087
Lead, commercial.....................	1 undrawn .... 2 drawn	0·0126
Reostene, Glover.....................	1 undrawn .... 2 drawn	0·173
Platinoid ,, ...	1 drawn .... 2 undrawn	0·533
German silver, Glover	1 drawn .... 2 undrawn	0·105
Manganin, Glover.....................	1 drawn .... 2 undrawn	0·031

10. The resistances of all the undrawn wires were carefully determined by the usual bridge method.

The specific gravities and cross sections of both the undrawn and drawn wires were also determined by weighing known lengths in air and in water. The values are given in the following table. It will be noted that the specific gravity of drawn copper, of drawn commercial lead, of drawn platinoid, and of drawn manganin, is greater* than for the corresponding undrawn wires; that the specific gravity of undrawn and drawn German silver wire is the same; and that the specific gravity of drawn reostene wire and of drawn pure lead wire is less than that of the undrawn.

* Average about a half per cent.

Metal.	Cross section of undrawn and drawn wires.	Specific gravity of undrawn and drawn wires.	Resistance of the undrawn wires, in C.G.S. units, at the temperature stated.	
			Per cubic centi-metre.	Per centimetre long, weighing a gram.
	sq. cm.			
Copper, Johnson and Matthey, No. 1	0·01172 0·00218	8·9607 8·996	1680	15050 at 13° C.
Copper, Johnson and Matthey, No. 2	0·01171 0·002233	8·856 8·897	4665	41310 at 13·5° C.
Copper, Johnson and Matthey, No. 3	0·01174 0·002086	8·963 9·05	1859	16660 at 13·5° C.
Copper, hard, Glover	0·0116 0·002018	8·923 8·982	1760	15700 at 17° C.
,, soft ,,	0·006506 0·002421	8·898 9·074	1681	14960 at 17° C.
,, laboratory	0·01192 0·002458	8·832 8·908	1764	15580 at 17·5° C.
Lead, pure........	0·01145 0·002448	11·25 11·15	20770	233600 at 14·5° C.
,, commercial ..	0·01181 0·002404	11·14 11·23	22100	246200 at 15° C.
Reostene	0·01142 0·002531	7·862 7·667	77230	607100 at 17·2° C.
Platinoid	0·01114 0·002316	8·74 8·78	40570	354600 at 17·3° C.
German silver	0·0116 0·002295	8·756 8·755	32340	283100 at 17·5° C.
Manganin.........	0·0116 0·002443	8·515 8·58	41040	349400 at 17·2° C.

11. The resistances of the drawn copper and manganin wires were compared with the resistances of the corresponding undrawn copper and manganin wires by the fall of potential method, and it was found that the resistances of the drawn wires (for the same length and cross section) were slightly greater* than that of the undrawn wires. In calculating the total resistance in the circuit external to the galvanometer, this increase of resistance in the drawn wire is not taken into account. The circuit consisted of 60 cm. of the undrawn wire, and 60 cm. of the drawn wire, together with the low resistance galvanometer. By multiplying the current per division, given in the table of Section 9, by the total resistance of the circuit, the thermo-electric difference per degree between drawn and undrawn wires is found. The numbers are given in the following table :—

* Less than 1 per cent.

Metal.	Resistance in international ohms of 60 cm. of wire.		Total resistance external to galvanometer.	Total resistance in circuit.	Thermo-electric difference in mikrovolt per degree of difference of temperature.
	Undrawn.	Drawn.			
Copper, Johnson and Matthey, No. 1 ..	0·0086	0·0462	0·0548	1·555	0·0089
Ditto, No. 2 ..	0·0239	0·1254	0·1493	1·649	0·0460
Ditto, No. 3	0·0095	0·0536	0·0631	1·563	0·0163
Copper, hard, Glover	0·0091	0·0523	0·0614	1·561	0·0106
,, soft, ,,	0·0155	0·0417	0·0572	1·557	0·0483
,, laboratory ..	0·0089	0·0431	0·0520	1·552	0·0675
Lead, pure	0·1088	0·5043	0·613	2·113	0·0184
,, commercial ...	0·1123	0·5517	0·664	2·164	0·0273
Reostene	0·4058	1·831	2·237	3·737	0·6465
Platinoid...........	0·2186	1·052	1·271	2·771	1·477
German silver	0·1673	0·845	1·013	2·513	0·2638
Manganin..........	0·212	1·008	1·220	2·720	0·0843

12. The copper wires numbered 1, 2, 3, of Messrs. Johnson and Matthey were also tried undrawn.

Conductors.	Direction of current through hot junction.	Current in mikroampere per division up to 100° C.	Difference of potential per degree in mikrovolt.
Copper, Messrs. Johnson and and Matthey, Nos. 1 and 2	2 to 1	1·099	1·667
Ditto, Nos. 2 and 3	2 to 3	0·48	0·743
Ditto, Nos. 3 and 1	3 to 1	0·62	0·942

13. The effect of hardening by twisting has been partially tried. Thus two pieces of laboratory copper wire were taken, and one was in successive experiments twisted 1 turn, 3 turns, 5 turns, 7 turns, $8\frac{1}{2}$ turns per cm. The wire with $8\frac{1}{2}$ turns per cm. got quite brittle, and broke when an attempt was made to put more twists into it. The twisted wire was then heated red hot by an electric current, and allowed to cool. This partially annealed it.

The results are given in the following table :—

Number of turns in twisted wire per centimetre.	Thermo-electric difference between untwisted and twisted copper wire in mikrovolt per degree.
1	0·0054
3	0·0223
5	0·0262
7	0·0419
8·5	0·0594
8·5 and partially annealed	0·0345

14. The effects of twist on the drawn copper wire were also tried, and it was found that 1, 2, 3 turns per cm. in the drawn wire slightly diminished the thermo-electric difference obtained between the undrawn wire and the drawn wire; but that 4 and 5 turns per cm. in the drawn wire gave the same thermo-electric difference as was found between the undrawn wire and the untwisted drawn wire.

15. The drawn and twisted copper wire was annealed by putting a gradually increasing current through it till it got red-hot, and then, without breaking the circuit, the current was gradually reduced till the wire was at the temperature of the laboratory. Trying it in this condition along with the undrawn and untwisted copper wire, the current through the hot junction was found to be reversed, being from the drawn twisted and annealed wire to the undrawn wire. The thermo-electric difference was 0·0081 mikrovolt per degree.

16. Similar experiments on platinoid wires as those described in Section 14 on copper wires gave similar results. Thus 1, 2, 3 turns per cm. in the drawn platinoid wire diminished the thermo-electric difference obtained between the drawn wire and the undrawn wire; but 4 and 5 turns per cm. in the drawn wire gave the same thermo-electric difference (1·477 mikrovolts per degree) as was found between the untwisted drawn wire and the undrawn wire.

17. The drawn and twisted platinoid wire was partially annealed, and the thermo-electric difference between it and the undrawn platinoid wire was thereby reduced from 1·477 mikrovolts per degree to 0·567 mikrovolt per degree.

18. A beginning has been made of determining the thermo-electric differences between free wires and wires previously permanently elongated 1, 2, 3, &c. per cent. by a simple longitudinal stress; also wires while (*a*) under stress, stretching them within their limits of elasticity; and (*b*) under stress, stretching them beyond their limits of elasticity. I hope to be able soon to communicate the results to the Society.